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The Effect of Artificial Lights on Fish and other Marine Organisms at Sea

By J. H. S. BLAXTER, M.A. and B. B. PARRISH, B.Sc.

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The Effect of Artificial Lights on Fish and other Marine Organisms at Sea

INTRODUCTION

Artificial lights are used extensively in fishing operations in different parts of the world (Schärfe 53, Anon. 1955, Borisov, 1955, 1956). Their use is probably greatest in Japan where important "light" heries for a number of species of fish have existed from the earliest times. Lights are also used extensively the Mediterranean, especially in the sardine fisheries. Hitherto, however, the use of lights in the ner European sea fisheries has been on a relatively limited scale. Jenkins (1927) reports that lights re used by Dutch fishermen to attract herring in the fifteenth century but they are not used by those hermen today. Norwegian fishermen use them in their purse-seine fishery (Anon. 1948, Dragesund, rsonal communication) and they are sometimes used by the Scottish ring-net fishermen to drive herring ay from inaccessible places near the shore.

Experimental and commercial techniques for catching fish aggregated by lights are described by rious workers (e.g. Schärfe 1953). While most techniques require the positive attraction of fish to the ht, a repellent action in adult herring is used by Scottish ring-net fishermen. Lift nets or blanket nets catching the aggregated fish are used off Japan and in other regions (Takayama 1949, Radovich and bbs 1954, Anon. 1955, Borisov 1956). The use of a fish pump associated with an electrical fishing paratus for sucking up small herring 7 to 8 cm (about 3″) long aggregated by lights has been described Smith (1955) and a fish pump is also described by Borisov (1956) and Nikonorov (1957).

Since the war a number of experimental studies have been made, in the North Sea and adjacent ters, on the effect of artificial lights on fish (Krefft and Schubert 1950, Parrish and Craig 1951, Schüler d Krefft 1951, Craig and Baxter 1952, Richardson 1952, Anon. 1953). Experimental work with lights Atlantic herring did not yield any positive result in the last century (Mitchell 1864). Krefft and Schubert 950) reported the attraction of young herring to the surface by a 100 watt light. Day (personal com- unication) attracted herring up to 10 cm (4″) long to the surface on the east coast of America with hts from 5 to 1000 watts. Richardson (1952) found that shoals of adult herring at North Shields, East glia and Cape Griz Nez descended 20-30 feet below their original depth when a 60 watt light was one into the water. Piskunov (1949) reported attraction of Pacific herring by a 100 watt light.

Of species related to herring Richardson also found that pilchards were attracted by a 60 watt light d Radovich and Gibbs (1954) that juvenile sardines and anchovies were attracted by lights of 750 tts.

The objectives of work with lights carried out from Aberdeen since 1952 have been:—

(a) to study the behaviour of fish in response to lights and other factors

(b) to investigate the possibilities of using lights to attract or repel fish, particularly herring, as an aid to commercial fishing

(c) as a secondary objective, to assist in interpreting echo-traces.

METHODS

NERAL

Fifty-nine experiments have been carried out in the period 1953-1957 in addition to others before series was started. Thirty-one of these experiments were conducted off the east coast of Scotland l 28 off the Scottish west coast. The depth of water varied from 4 to 110 m (2 to 60 fm) the most al depths being between 25 and 60 m (13 to 33 fm).

Details of the dates and places of light experiments are given in the appendix. In many instanc the places were chosen because it was known that concentrations of fish were present there, but in oth lights were used in the hope that fish might be present.

Lights

Lights of different intensities and colours were used. Usually they were used under water betwe the surface and 50 m (27½ fm) but in some cases lights were used above the surface. The reactions fish and other organisms to different light stimuli were then observed by echosounder. These were various types: in F.R.S. *Clupea*, Kelvin & Hughes' M.S.22 (30 kc/s.) and M.S.26B (14 kc/s.) and in F.R *Scotia* M.S.24 (30 kc/s.). When at the surface the reactions of fish were observed by eye. In some ca the lights were used on shoals already located by echosounder, in others aggregations were produced the lights themselves.

Bulbs between 15 and 100 watts were housed in watertight cases consisting of a brass base fitted wi a watertight gland for the cable (see Fig. 1). The bulb was surrounded by a well glass with a grou glass rim which fitted into a groove in the base, the join being made watertight with high vacuum grea

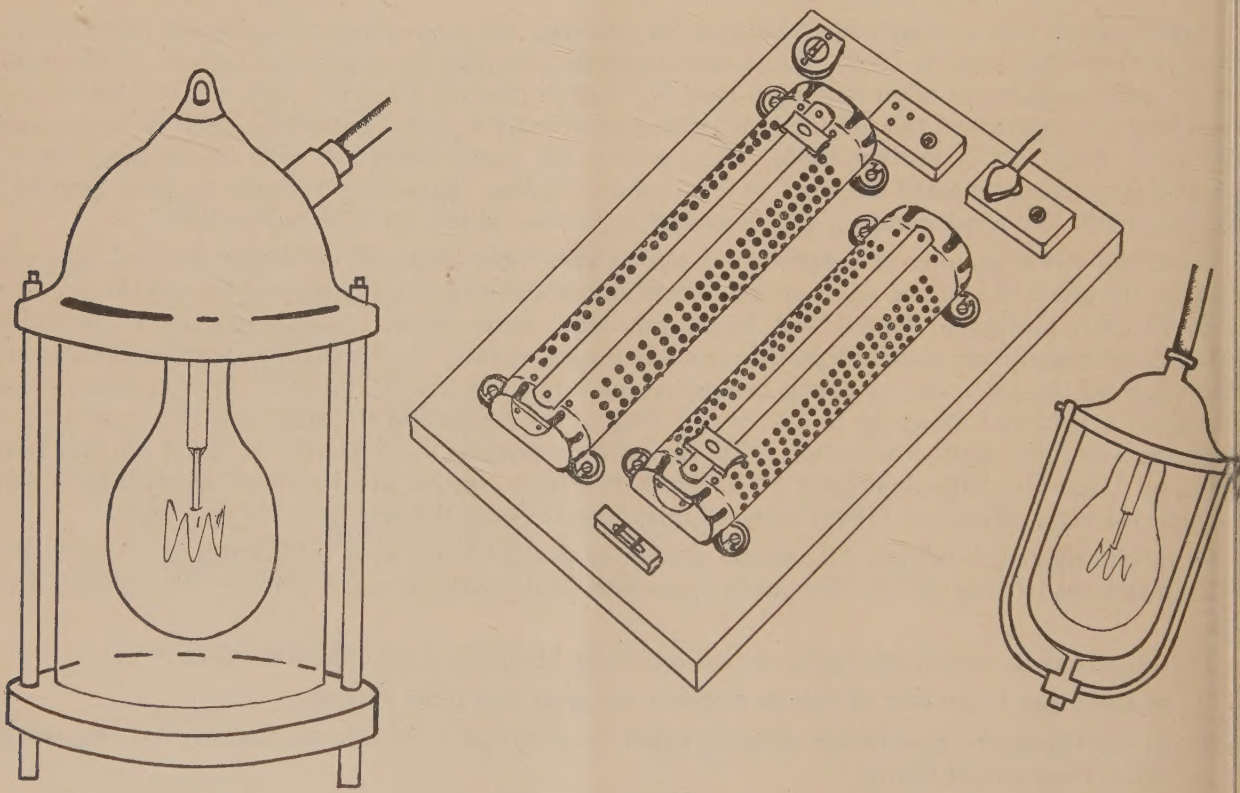

Fig. 1 Apparatus used in the light experiments. Left, holder for 1 kw and 1½ kw bulbs; middle, variable resistance unit; right, holder for bulbs from 100 to 15 w.

The light produced by these bulbs shone in all directions except immediately above. Bulbs of 1000 wa and over were housed in a larger case which consisted of a vertical glass cylinder with cast fittings both ends. Most of the light was thus distributed in a horizontal plane although sometimes the lig cylinder was hung horizontally. Owing to the movement of the vessel and tide the lights tended to swin whether mounted vertically or horizontally.

Different light intensities were obtained first from lights of different wattage but later rheostats ere used. Besides tungsten filament lamps with clear and opaque glass, coloured bulbs were used. he colours were produced by painting tungsten filament bulbs red, blue, green or yellow. Ultra-violet ght was obtained by a 125 watt "black" bulb.

AMPLING OF AGGREGATIONS

The methods used in these experiments for identifying and sampling the organisms aggregated by ıe lights were as follows:—

1. *Observations at surface.* In many instances, particularly when lights were at, or near, the surface, organisms could be identified by eye in the water or on board ship after removing them from the water with scoop nets.

2. *Underwater photography.* A 35 mm Robot camera in an underwater case and fitted with an electronic flash (Craig 1952) was used for photographing aggregations. The duration of the flash was about 1·5 milliseconds, which did not appear to disturb the aggregations. Photographs of fish aggregated by a light (in Experiment 2) have already been published (Craig 1955).

3. *Underwater television.* On two occasions in 1952, in co-operation with staff from the Scottish Marine Biological Association at Millport, an underwater television apparatus (Barnes 1952) was used on aggregations. There were some difficulties as the high light intensities used (up to 2000 watts) tended to aggregate the fish at too great a distance from the camera. However, numerous plankton species were identified by this gear and whiting were seen on one occasion.

4. *Drift nets.*
   a. By drift nets shot in the conventional manner;
   b. by drift nets shot from the stern when at anchor.

5. *"Blanket" or "lift" nets.* A "blanket" or "lift" net was designed on the basis of that described by Radovich and Gibbs (1954) and used extensively in the Japanese stick-held dipnet fishery (Anon. 1955). The net was about 15 m (50′) long and 27 m (90′) deep and was suspended over the port side of the vessel. Two booms about 12 m (40′) long projected out over the port side. The bottom of the net, which was hanging in the water below the vessel, could be pulled up by ropes which passed through blocks on the end of the booms and on to the deck. This made a bag of the net and trapped fish near the surface alongside.

6. *Boom net.* A boom net, similar to that used from small anchored vessels in the River Forth (see chapter by Wood in Graham 1956), was also tried. This was a funnel-shaped net about 27 m (90′) long with its mouth kept open by two horizontal booms, one near the surface and the other, weighted, at the bottom of the net. The booms and net were shot over the bows of the vessel when at anchor and were kept open by the tide. A tide of about 0·5 m/sec (1½ feet/sec) or more was required to keep the net open. The mouth of the net was 6 m (20′) across and between 2 and 10 m (7′ to 33′) in depth.

7. *Explosives.* This was the most successful method of sampling especially when the aggregations were within 10-15 m (30-50′) of the surface. A small charge (60-250 g or 2-8 oz) of submarine gelatine was exploded electrically at a depth of at least 9 m (30′) below the keel. In some instances detonators alone were used at or near the surface and proved adequate to stun small fish.

   Explosives were not very satisfactory in a strong tide unless a small boat with an outboard motor was available to pick up the catch. Care also had to be taken to weight the charge adequately in a strong tide to prevent it being exploded too near the surface.

8. *Fishing lines.* Lines, with baited or unbaited hooks, were used extensively for sampling. Th were particularly valuable for showing the depth at which fish were caught.

9. *Two-metre net.* A two-metre (6½′) ring fitted with a fine mesh net was used when at ancho It was hauled from bottom to surface by winch at speeds from 0·5-1·0 m/sec (1½-3 feet/se This method was generally unsuccessful due probably to the avoidance of the net by t aggregated organisms.

RESULTS

Description of a Light Experiment

While a full summary of the light experiments carried out since 1953 is given in the appendix, t following account is given of one experiment (No. 1) to illustrate the experimental procedure and t types of result obtained. The echo-trace is shown in Plate I.

The experiment was carried out from F.R.S. *Clupea* in Loch Striven (upper Firth of Clyde) on 23 and 24th February 1953. The vessel anchored in 66 m (36 fm) during the afternoon near some ech traces. The sky was overcast and no moon was visible during the experiment. The progress of t experiment was then as follows:

Reference on echo-trace	Time	Action. (Depths given from surface, not from oscillator, in metres and fathoms)	Result of carrying out action in previous column. (Depths given from surface to top of echo-trace in metres and fathoms)
1	1820 (Dusk) 23/2/57	100 watt blue light switched on at 37 m (20 fm).	1. After about 15 min a "spotty" trace appeared near the surface. 2. After about 60 min a continuous trace appeared at about 45 m (24 fm) gradually increasing in density.
2	2006 (Dark and cloudy).	100 watt blue light raised to 27 m (15 fm).	1. Spotty trace decreased in intensity and disappeared. 2. Continuous trace rose to 27 m (15 fm).
3	2025	100 watt blue light raised to 18 m (10 fm).	1. Spotty trace absent. 2. Continuous trace rose to 18 m (10 fm).
4	2050	100 watt blue light raised to surface.	1. Spotty trace appeared at about 5 m (3 fm). 2. Continuous trace rose to 5 m (3 fm). (After 12 min. sprats seen at surface.)
5	2135	100 watt blue light lowered to 18 m (10 fm).	1. Spotty trace disappeared. 2. Continuous trace descended to 25 m (13 fm). N.B. Descent more rapid than ascent.
6	2145	100 watt blue light lowered to 37 m (20 fm).	1. Spotty trace appeared above light. 2. Continuous trace descended to 38 m (21 fm).

Reference on echo-trace	Time	Action. (Depths given from surface not from oscillator, in metres and fathoms)	Result of carrying out action in previous column. (Depths given from surface to top of echo-trace in metres and fathoms)
7	2155	125 watt ultra-violet light switched on at 27 m (15 fm). 100 watt blue light switched off.	1. Spotty trace at about 10 to 18 m (5 to 10 fm). 2. Continuous trace rose to 18 m (10 fm).
8	2210	125 watt ultra-violet light lowered to 38 m (21 fm).	1. Some spots at about 15 m (8 fm). 2. Continuous trace decreased in width.
9	2235	125 watt ultra-violet light raised to 9 m (5 fm). 100 watt blue light switched on at 37 m (20 fm).	1. Entire trace dispersed followed by the appearance of two traces, a lower continuous trace at 40 m (22 fm) and an upper more spotty trace at 18 m (10 fm).
10	2255	125 watt ultra-violet light switched off. 100 watt blue light still on at 37 m (20 fm).	1. Upper trace decreased in intensity. 2. Lower layer trace disappeared and reformed at about same depth (37 m (20 fm)).
11	2317	125 watt ultra-violet light removed. 100 watt red light switched on at 18 m (10 fm). 100 watt blue light still on at 37 m (20 fm).	1. Upper spotty trace moved down below red light to 22 m (12 fm). 2. Lower layer trace remained at 37 m (20 fm).
12	2330	100 watt blue light raised to 18 m (10 fm). 100 watt red light still on at 18 m (10 fm).	1. Spotty trace disappeared. 2. Lower continuous trace rose, extending from 18 to 33 m (10 to 18 fm).
13	2348	100 watt red light switched off. 100 watt blue light still on at 18 m (10 fm).	No effect.
14	0008 24/2/57	100 watt blue and red lights removed. 100 watt blue light then lowered to 18 m (10 fm) and switched on.	1. Spotty trace absent. 2. Continuous trace rose slightly and then descended to 22 m (12 fm).
15	0016	100 watt red light lowered and switched on at 33 m (18 fm). 100 watt blue light still on at 18 m (10 fm).	1. Spotty trace absent. 2. Continuous trace developed at 33 m (18 fm) and a less dense trace at 24 m (13 fm).
16	0040	Lights interchanged.	1. Spotty trace absent. 2. Lower continuous trace rose temporarily and then descended to 37 m (20 fm).
17	0055	100 watt red light raised to 9 m (5 fm). 100 watt blue light still on at 33 m (18 fm).	1. Spotty trace absent. 2. Slight rise, followed by thickening of upper continuous trace. Lower continuous trace remained stationary.

Reference on echo-trace	Time	Action. (Depths given from surface not from oscillator, in metres and fathoms)	Result of carrying out action in previous column. (Depths given from surface to top o echo-trace in metres and fathoms)
18	0110	100 watt red light switched off. 100 watt blue light still on at 33 m (18 fm).	1. Spotty trace absent. 2. Upper continuous trace descende slightly. Lower continuous trac remained stationary.
19	0128	100 watt white light lowered to 9 m (5 fm) and switched on. 100 watt blue light still on at 33 m (18 fm).	1. Spotty trace redeveloped at abou 9 m (5 fm). 2. Upper continuous trace descende to about 27 m (15 fm). Lowe continuous trace remained un changed at 37 m (20 fm).
20	0145	100 watt red light switched on at 9 m (5 fm). 100 watt white light still on at 9 m (5 fm). 100 watt blue light still on at 33 m (18 fm).	No effect.
21	0212 to 0312	Underwater camera used to take 21 exposures as follows: 1- 4 at 9 m (5 fm). 5- 7 at 12 m (6½ fm). 8-12 at 33 m (18 fm). 13-16 at 11 m (6 fm). 17-21 at 38 m (21 fm).	1. No effect on fish, spotty trace re mained from 9-18 m (5-10 fm and became very thick. 2. Upper continuous trace remaine at about 27 m (15 fm). Lower co tinuous trace remained at 37 t 46 m (20-25 fm). 3. Photographic exposures in upp trace showed small clupeoids, an in lower trace showed whiting.
22	0325	100 watt white light raised to surface. 100 watt blue and red light switched off.	1. Spotty trace rose to 6 m (3½ fm Small clupeoids were seen at su face so fish probably from surfa to 18 m (10 fm). 2. Upper and lower continuous trac joined and made up a thick trac from 22 to 34 m (12-18½ fm).
23	0400	250 g charge of submarine gelatine exploded at 11 m (6 fm).	1. Large concentrations of fis brought to surface, firstly herrin (12-17 cm, 5-7″) and sprats (5-1 cm, 2-5″), and later whitin (10-32 cm, 4-13″). 2. Trace dispersed slightly.

The conclusions that may be drawn from this experiment are as follow:

1. The trace which remained in the upper layers and was generally spotty in appearance w caused by small sprats and 0-group herring.
2. The layered traces were due to whiting and were usually deeper.
3. The whiting were more sensitive to changes in light stimuli and tended to aggregate bel the lowest light.
4. The clupeoids were most strongly affected by the 100 watt white light (which was the o giving the highest intensity). They were seen at the surface and whiting were not.

5. There seems to be no observable difference in the reactions of fish in this experiment to red and blue lights (both 100 watt). This was tested by interchanging the lights (0040 hours) when the general pattern of the traces remained unchanged.
6. Fish reacted to light from a 125 watt ultra-violet bulb but this may have been due to fluorescence from micro-organisms in the water.
7. Descent seemed to be more rapid than ascent.

In measuring the depth of traces the distance is taken from the surface to the top of the trace. The ho paper only shows the distance from the oscillator to the trace; this distance may or may not be a rtical one. Thus if a light is shown on the paper with a trace below it, the trace may, in fact, be below e light, or it may be to one side, at a distance from the oscillator exceeding that of the light from the cillator.

In these experiments it has been assumed that the traces are vertically below the lights, and move rtically when the lights are moved, for the following reasons:

1. Sampling by line, explosives, photography, etc. show organisms are below the light.
2. The transmission cone of the echosounder is such that the trace might be expected to disappear if the movements of lights up or down resulted in a sideways scatter of the organisms. This sometimes happens, but only temporarily, which points to the resultant movements being vertical.

ECIES AGGREGATED BY LIGHT

A list of species sampled in the experiments is given in Table I.

TABLE I
Species aggregated

Species	Times sampled on west coast	Times sampled on east coast	Length cm (inches in brackets)	Numbers observed or sampled
Gadus merlangus (whiting)	15 (+2?)	5	10-40 (4-16)	Few to thousands
Gadus minutus (poor cod)	2	—	11 (4½)	20-60
Gadus virens (saithe)	1	—	?	12
Gadus callarias (cod)	1	1	20-60 (8-24)	1-10
Gadus poutassou (poutassou)	1?	—	?	None
Molva vulgaris (ling)	1	—	?	1
Merluccius vulgaris (hake)	1	—	?	1
Clupea harengus (herring)				
larvae	1?	2 (+1?)	3-5 (1-2)	1-10
0 group	2	8	6-15 (2½-6)	Few to thousands
1 group	4	6	16-25 (6½-10)	Few to hundreds
Clupea sprattus (sprat)	6	6	5-15 (2-6)	Few to thousands
Unidentified clupeoids	5	3	?	Few
Anguilla vulgaris (elvers)	1	—	?	Not known
Trachurus trachurus (horse mackerel)	1	1	c. 25 (10)	1
Scomber scombrus (mackerel)	2	—	35-40 (14-16)	1-30
Ammodytes lanceolatus (greater sand eel)	6	1	c. 4 (1½)	1-10
Motella mustela (five bearded rockling)	—	2	7·5-10 (3-4)	1-5
Gobius minutus (common goby)	2	—	c. 4 (1½)	1-5

TABLE I (*Continued*)
Species aggregated

Species	Times sampled on west coast	Times sampled on east coast	Length cm (inches in brackets)	Numbers observed or sampled
Gasterosteus aculeatus .. (three spined stickleback)	1	—	c. 4 (1½)	5
Acanthias vulgaris .. .. (picked dogfish)	1	—	c. 30 (12)	1
Unidentified dogfish ..	1	—	?	1
Euphausiids				
Nyctiphanes couchii ..	1	—	—	1
Meganyctiphanes norvegica	1 (+1?)	—	—	1-many
Unidentified	3	—	—	?
Mysids				
Siriella norvegica	1	—	—	1
Decapods				
Crangon vulgaris	3	—	—	1-10
Polychaets				
Heteronereids	4	2	—	1-10
Alloteuthis media	1	—	—	1
Chaetognaths				
Sagitta spp.	1	—	—	Many

Initial Aggregations

In some cases experiments were started with no trace present, in others traces of fish were visi when the experiment started. A summary of these is given in Table II.

TABLE II
Initial aggregations

Shoals present on anchoring or stopping	Aggregations appearing after anchoring or stopping		No aggregations obtained with or without lights
	When lights used	Before lights used	
4	22	19	14

In four cases the ship anchored or stopped when a trace was picked up and the trace remai below the ship. In most cases the trace appeared after stopping (though the ship often stopped in area where traces had been seen). Out of the 19 instances when traces appeared before lights were us in seven the trace increased in intensity under the influence of lights.

The types of lights which were used for initially aggregating traces are analysed further in Ta III.

TABLE III
Analysis of lights used for aggregating

Type of light	Average depth used (metres, fathoms in brackets)	Range of depths used (metres, fathoms in brackets)	Times used	Number of times aggregations obtained	Average time taken to cause aggregations (mins)	Range of times taken to cause aggregations (mins)
1500 w. white	46 (25)	—	1	1	4	—
1000 w. white	6 (3½)	0-27 (0-15)	32	18	32	0-120
125 w. u/v	23 (12½)	9-37 (5-20)	2	2	6·5	1-12
100 w. blue	15 (8)	2-37 (1-20)	21	8	33	0-68
100 w. red	9 (5)	—	1	1	0	—
100 w. green	0	—	1	1	0	—
60 w. blue	7 (4)	4-9 (2-5)	5	2	6	2-10
15 w. blue	7 (4)	2-13 (1-7)	4	nil	—	—

There was a tendency for the 1000 watt light to be more effective in producing aggregations but re does not seem to be much difference between the time taken to do so by this and the lower intensities. s to be expected that bright lights should be more effective as they will have a greater range and so ect fish in a much greater volume of water. This is borne out in six instances when the 1000 watt nt produced aggregations after lower intensity lights had failed.

FECT OF INTENSITY

Apart from the effect of light intensity in producing the initial aggregations, the reactions of different cies, once aggregated, varied with the light intensity.

Gadoids—Gadus merlangus (*whiting*)

In no case were whiting seen at the surface around a light and in general they aggregated some tance away from the light even with the lowest intensity used.

Data obtained on two nights in Loch Striven (55, 56) may be used to show the reactions of whiting length 14 to 23 cm (5½-9″) to different light intensities obtained from two tungsten filament bulbs. ble IV shows the distance from various lights at which fish were located. The two different lamp sings were used but were arranged so that the lights were directed vertically.

TABLE IV

The effect of intensity on the distribution of whiting

Intensity of light (candle power)	Distances of tops of aggregations from the light (metres)	
	Experiment 55	Experiment 56
1000 (1000 watt bulb)	18·3	18·3, 15·6, 14·6
750 (1000 watt bulb dimmed by rheostat)	16·5	13·7
500 (1000 watt bulb dimmed by rheostat)	15·6	12·8
250 (1000 watt bulb dimmed by rheostat)	12·8, 12·8	11·0
100 (1000 watt bulb dimmed by rheostat)	10·1	9·2, 9·2
100 (100 watt bulb)	13·7, 13·7, 10·1	11·9, 10·1
50 (100 watt bulb dimmed by rheostat)	10·1	8·2
25 (100 watt bulb dimmed by rheostat)	8·2	5·5
10 (100 watt bulb dimmed by rheostat)	5·5, 4·6	5·5

a water absorbs light according to an exponential law such as that in a parallel beam of light, if the ensity at any distance be I_0, than at a further distance x, the intensity will be reduced to I_x and will given by:

$$I_x = I_0 e^{-cx} \quad \ldots\ldots\ldots\ldots 1$$

here c is the extinction coefficient which will depend on the wavelength of light, turbidity etc. (see erdrup *et. al.* 1946). When a 'point' source is used (as in these experiments) and the light diverges, intensity also decreases with distance from the source according to the inverse square law, and the ationship becomes:"

$$I_x = \frac{I_0 e^{-cx}}{x^2} \quad \ldots\ldots\ldots\ldots 2$$

$$\text{or } \log_e I_0 - 2\log_e x = \log_e I_x + cx \quad \ldots\ldots\ldots\ldots 3$$

ere I_0 is the intensity of the light source, I_x is the intensity of light at a distance x from the source and the extinction coefficient. The experiments were done on moonless nights and thus light came only m the experimental source.

If there is a general relationship in Table IV such that whiting tend to aggregate at an optimu intensity the data presented in Table IV, if transformed according to equation 3, should yield a line plot with slope c. In Fig. 2 the values for $\log_e I_0 - 2\log_e x$ taken from Table IV are plotted against t corresponding values for x. To obtain a general relationship all the values are plotted regardless of da and type of light used.

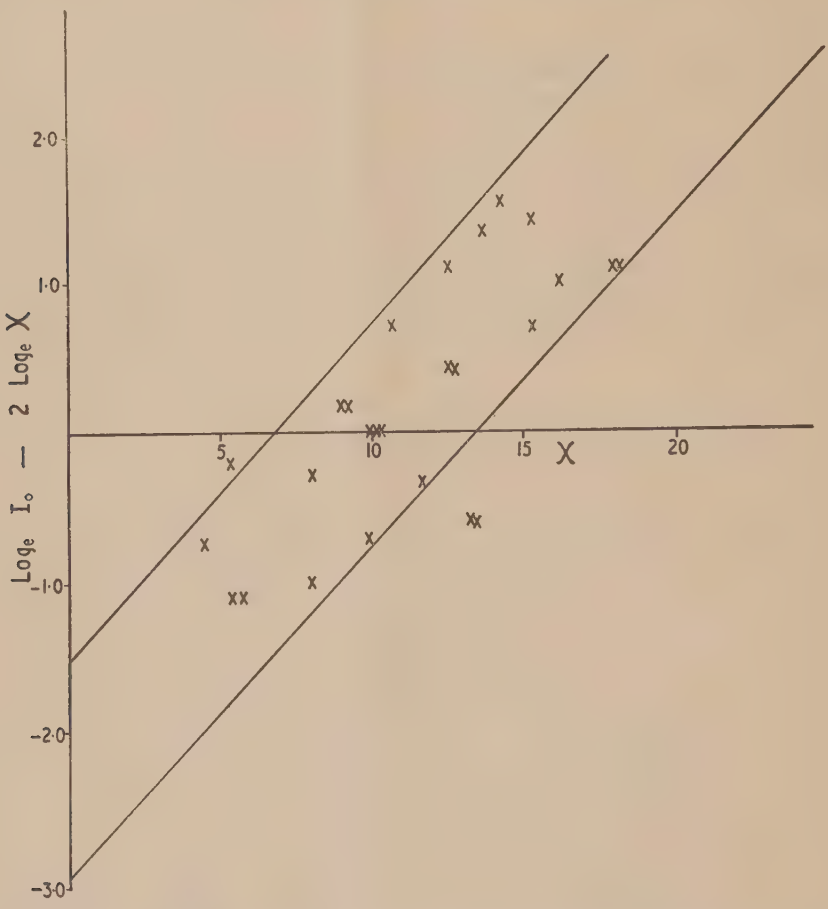

Fig. 2 The effect of light intensity on the distance of whiting aggregations from lights. Log$_e$ I_0—2 log$_e$ x is plotted against x, where I_0 is the power of the light source and x the distance in metres from the light source to the aggregation.

The points in Fig. 2 while showing a fairly wide scatter are distinctly linear. Lines of equal sl enveloping the main body of points are shown drawn by eye. The slope of these lines, representing average extinction coefficient, c, was obtained in the following way. Two tungsten filament light different intensities were lowered into the water until they became invisible to the observer on de It was found that a lamp of 100 C.P. disappeared at a depth of 35 m (19 fm) and a lamp of 10 C at 27 m (15 fm). Now if it is assumed that both lights cease to be visible at the same intensity I_Δ, t from equation 2:

$$\frac{100e^{-c.35}}{35^2} = I_\Delta = \frac{10e^{-c.27}}{27^2}$$

therefore c=0·22

Values of $\log_e I_x$ for both lines were then obtained from their intercepts on the y axis (at wh point $\log_e I_0 - 2\log_e x = \log_e I_x$). This gave values of $\log_e I_x$ between −1·5 and −2·9 corresponding values of I_x between 0·219 and 0·055 lux (metre candles).

It may therefore be said that there is a general optimum intensity at which the whiting aggregati occur; this lies between 0·2 and 0·05 lux, i.e. of the order of 10^{-1} lux. The wide scatter of points in Fig

ıay be due to a number of reasons. Table IV shows clearly that there was a difference between the alues for the two nights on which the experiment was carried out. There was also a difference in reaction) a 100 watt bulb acting as a 100 C.P. source and a 1000 watt bulb dimmed by a rheostat to act as a 00 C.P. source. This is presumably due to the increase in light at the red end of the spectrum, when ıe light is dimmed, which will result in less penetration of light into the water and a consequent reduction ı the distance of the aggregation from that source.

Of interest is the fact that the extinction coefficient calculated from observation by the human ye (obtained by lowering lights into the water) obviously agrees well with the extinction coefficient btained from the movements of whiting (i.e. the slope of the line given by the points in Fig. 2 if drawn y eye). This suggests that the whiting are reacting to the same light as the human eye. It has been ıown that the spectral sensitivity curve for marine fish is similar to that of man (see Prosser *et al.* 1950).

During the period of daylight between these two light experiments the whiting sank to a depth f about 50 m (27½ fm). It is possible to calculate the intensity of light at this depth and see how it com- ares with the optimum found during the night. The day was a dull one, the intensity of illumination eing about 10^4 lux. Therefore using the same extinction coefficient, 0·22, the intensity at 50 m (27½ n) may be calculated from equation 1.

$$I_x = 10^4 e^{-0.22 \times 50} = 0.17 \text{ lux}$$

Thus the whiting moved down at dawn so that they remained within the same order of light intensity s that during the light experiments.

. *Clupeoids*

The reactions of 0-group and 1-group herring and sprats to lights were quite different from whiting. Hey were nearly always found immediately around the light, whatever its power. By bringing the light) the surface the fish could be seen from the deck. An analysis of the results of experiments in which lupeoids were observed is given in Table V. It will be seen that on all but three occasions clupeoids ere observed at the surface around the lights. On those three occasions clupeoids were identified below ıe lights by explosives.

TABLE V

Observations on clupeoids around lights

Species	Size	Number of experiments when observed around lights		Number of experiments when not observed around lights	
		East Coast	West Coast	East Coast	West Coast
C. harengus (herring)	16-25 cm (6½-10″)	2	2	1	0
	5-15 cm (2-6″)	7	1	0	0
	<5 cm (2″)	2	0	0	0
C. sprattus (sprat)	5-16 cm (2-6½″)	3	4	0	0
Unidentified	—	1	0	1	1

3. *Other organisms*

It was often difficult to estimate the position of some species in relation to light due to the "blanketing" effect of organisms such as whiting, which were present in much greater numbers. However, a list may be given of species seen at the surface around lights of all types (mainly 1000 watt light).

Teleosts	—	*Ammodytes lanceolatus* (larvae)
		Motella mustela
		Gasterosteus aculeatus
		Gobius minutus
		Anguilla vulgaris (elvers)
Crustacea	—	*Nyctiphanes couchii*
		Meganyctiphanes norvegica
		Siriella norvegica
		Crangon vulgaris
Mollusca	—	*Alloteuthis media*
Annelida	—	Nereids (heteronereid stages)

Instances of fish such as adult mackerel and skate being seen at the surface were possibly due to the presence of food organisms there.

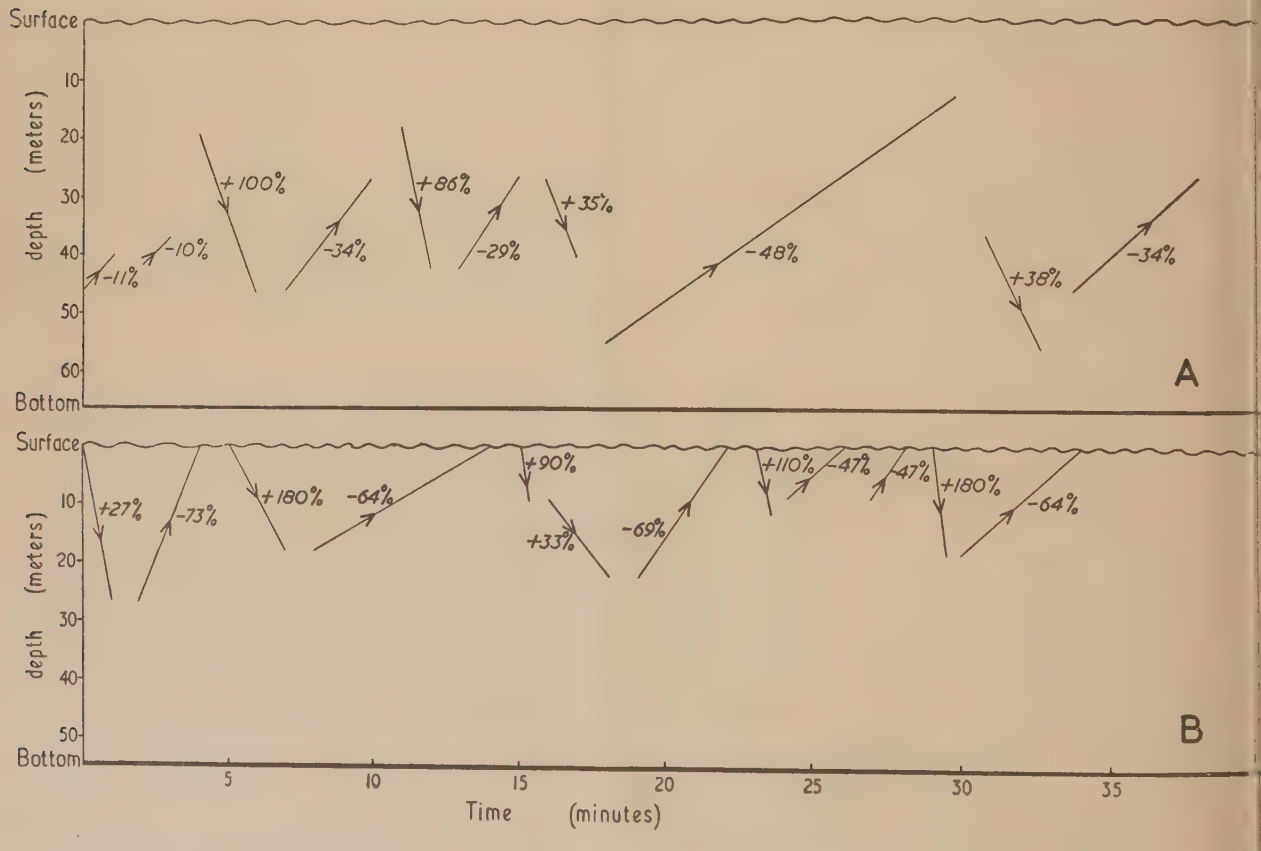

Fig. 3 Diagram to show the rate of movement and pressure changes undergone by fish during two light experiments.

A. Whiting (14·0-28·0 cm long) in L. Striven (11.3.53)

B. Herring (18·0-25·0 cm long) in L. Nevis (13.12.55)

The times refer to the *movements* only i.e. the time *between* each movement shown may vary from 1-30 minutes but is shown as a constant time of about one minute.

Effect of Colour

Difficulties were encountered in getting light filters of a suitable type to cover the well glasses or glass cylinder used in the underwater lights. Thus painted bulbs were used which did not give pure colours. Because of this and also because painted bulbs gave a much reduced light intensity as compared with unpainted bulbs, it is not easy to analyse any effect due to colour. (Painted blue bulbs produced only 2% of the light given by an unpainted bulb of similar wattage.)

The problem is further complicated by the differential absorption of colours by sea water, and the difficulty of getting a satisfactory light measuring device of suitable sensitivity to the different colours.

Despite these difficulties it may be said that no differences in behaviour were observed which could be ascribed to the effect of using different colours. Positive aggregations were obtained by ultra-violet light but in every case this could be ascribed to the resulting fluorescence from organisms in the water.

It should be mentioned that Craig and Baxter (1952) got immediate reactions using ultra-violet light, which indicates a reaction to the ultra-violet light rather than to visible fluorescence produced by it.

Vertical Migration and Pressure Changes

Observations were made on the extent of vertical migration and the pressure changes involved. Such pressure changes may well affect the behaviour of those fish which have to adapt themselves to pressure changes within the swim bladder.

Table VI gives details of the pressure changes over the whole series of experiments. In Fig. 3 examples are given of the vertical movements of herring and whiting in two light experiments (3, 37) with respect to change in pressure (allowing 1 atm=10 m (5½ fm)). Most of the movements took place within a period of 10 minutes or less. The movements which took place at dusk and dawn occupied periods up to three hours.

TABLE VI

Vertical migration and pressure changes in whiting and sprats

Stimulus causing movement	Percentage pressure change whiting (nos. of observations in brackets)				Percentage pressure change sprats (nos. of observations in brackets)			
	+ (descent)		− (ascent)		+ (descent)		− (ascent)	
	average	range	average	range	average	range	average	range
Artificial lights	39 (30)	9-100	28 (30)	10-49	69 (10)	22-225	39 (12)	11-67
Dawn or dusk	157 (5)	38-380	—	—	380 (1)	—	—	—

Vertical migration and pressure changes in herring

Stimulus causing movement	Percentage pressure change 0-group herring (5-15 cm, 2-6″) (nos. of observations in brackets)				Percentage pressure change 1-group herring (16-25 cm, 6½-10″) (nos. of observations in brackets)			
	+ (descent)		− (ascent)		+ (descent)		− (ascent)	
	average	range	average	range	average	range	average	range
Artificial lights	72 (12)	16-180	42 (12)	18-73	87 (9)	18-180	54 (8)	32-73
Dawn or dusk	—	—	66 (1)	—	380 (1)	—	66 (1)	—

It will be seen that the physostomatous species (herring and sprats) on the average underwe greater pressure changes than the whiting, which is physoclistous. Also it seems that all three species a able to withstand increases of pressure more readily than decreases. In every instance the positive valu are greater than the negative. This indicates that these fish find it easier to move down than to mo up.

This is to be expected as fish moving up towards the surface will either have to expel or resorb a depending on whether they are physostomatous or physoclistous. The chief obstacle in moving down the change in density of the fish due to compression of the swim bladder. Provided the fish is able maintain its position against this increase in density by movements of the fins, there is nothing to preve it making considerable downward movements.

The results shown in Table VI may be compared with those for the freshwater physoclistous per (Jones, 1951, 1952). Jones considers that perch can only swim freely within a zone whose depth is equiv lent to 16% reduction in pressure from the adapted pressure, and that for short periods of time th could undergo up to 33% reduction in pressure. In marine physoclistous fish he suggests the height f free swimming would be equivalent to a 22% reduction in pressure, and that diurnal migrations i volving a pressure decrease of more than 50% are unlikely to take place.

The results for whiting from these experiments show pressure decreases of up to 49% with an avera of 28%. Unfortunately no figures are available for the diurnal upward movement. These somewh higher figures may be explained in the light of Jones' results by the much greater strength of the whiting swim bladder than that of the perch. The even greater pressure changes experienced by herring a sprats are possible because these fish are physostomatous.

Vertical Swimming Speeds

These speeds were calculated from the echo-traces over the whole range of experiments. The tir for a given movement was measured either by stop-watch or by using information on the speed at whi the echo paper moves through the echo-sounder (usually about 0·6 cm/min).

The average speed in metres/minute for up and down movements in different species is given Table VII.

TABLE VII

Vertical swimming speeds

Species	Length	Temp.	Stimulus	*Speed in metres/minute (nos. of observations in brackets)			
				down		up	
				average	range	average	range
Gadus merlangus (whiting)	10-40 cm	4-10°C	Artificial light	10·8 (21)	1·6-56·0	5·5 (30)	1·5-14·6
,,	15-25 cm	4-10°C	Dusk or dawn	0·3 (5)	0·1-0·5	0·6 (1)	—
Clupea harengus (herring)	5-15 cm	4-10°C	Artificial light	17·9 (8)	0·9-36·0	6·1 (10)	0·8-13·5
,,	16-25 cm	4-10°C	Artificial light	22·8 (6)	6·5-36·0	6·5 (8)	3·0-13·5
Clupea sprattus (sprat)	5-15 cm	4-10°C	Artificial light	27·0 (1)	—	6·4 (11)	0·8-30·0

*Multiply by 3¼ to give feet/minute.

In general the downward swimming speeds are greater than the upward speeds which again sugge that the vertical swimming speeds are probably limited by the pressure changes involved. The high swimming speeds shown by clupeoids provide supporting evidence for this.

ACCOMMODATION

Inamura (1953), using an underwater light, found that shoals of *Trachurus japonicus* aggregated at ome distance from the light and then gradually moved towards it as they became accommodated to the ght source.

During the present experiments the organisms were usually presented with different stimuli at airly short time intervals and there was thus little time for accommodation to take place. In those nstances where light stimuli were presented for longer periods of time (from one to two hours) there were o signs of this accommodation effect and the organisms remained at an approximately constant distance rom the lights.

IZE OF AGGREGATIONS

The horizontal limit of the aggregations was determined by three methods:

1. By use of a portable Atlas (30 kc/s) or Bendix (50 kc/s) echosounder used from a small boat equipped with an outboard motor.
2. By moving a portable oscillator from one end of the research vessel to the other and observing any change in the amplitude of the echoes.
3. By observing changes in the trace when the research vessel weighed anchor after an experiment.

These observations were made towards the end of the series of experiments. In one experiment (51) n aggregation of whiting was found to extend about 5 m (16′) in all directions from a 1000 watt light. n two others (35, 36), aggregations which were probably whiting were found to extend about 20 m 65′) in all directions from a 1000 watt light. In another (32) where no underwater lights were used, a oncentration of whiting was found just aft of the research vessel which was lying at anchor in a tidal urrent. The fish in this instance were probably responding to the ship's lights which would not be isible immediately below the hull.

FFECTS OF EXTRANEOUS FACTORS

The following may be considered as other factors which might modify the behaviour of organisms ı these experiments.

1. *Ship's lights.* On a number of occasions aggregations were obtained without underwater lights, probably in response to the ship's lights (e.g. in experiments 7B, 9, 15, 32).
2. *Moonlight.* The light intensity due to the moon at the surface is less than one lux so that below the surface any light due to the moon would often be small compared with the intensities obtained from the underwater lights. It is possible that the moon might reinforce the light intensities from artificial lights which affect whiting. For instance in the experiments (55, 56) with different light intensities in Loch Striven, if the moon gave an intensity of 0·5 lux at the surface, the intensity at 10 m (5½ fm) would be 0·05 lux and at 20 m (11 fm) about 0·005 lux. These might be sufficient to modify slightly the movements of whiting aggregating in an optimum of about 0·1 lux.

   Clupeoids, however, aggregated at much higher intensities. While the moon might have a slight effect on the movements of whiting in a light experiment it is unlikely to affect clupeoids. Where artificial light stimuli are not in use, the moon, being the only source of light, may affect fish considerably (for instance Savage and Hodgson, 1934). Kawamoto and Uno (1954) report that the moon decreased the efficiency of their underwater lamps when aggregating *Trachurus trachurus.*
3. *Daylight.* Marked changes in the depth of fish were observed at dusk and dawn. Whiting and clupeoids were found to sink at dawn despite the use of artificial lights which had been

previously attracting them. This was probably due to the intensity at a particular dept being increased beyond the optimum. It was found possible, however, to obtain aggregation by artificial lights in daylight. For instance, an aggregation was obtained by 1000 wa light at 15 m (8 fm) in Loch Nevis (36).

4. *Tide.* A tidal current exceeding the maximum sustained swimming speed of a species woul prevent aggregations taking place. Such tides were found in the Inverness Firth and Riv Forth. The tide also affected the distribution of fish around lights, the aggregations tendi to be elongated and "downstream" from the light.

   The state of the tide also affected the success of failure of experiments, for fish movin backwards and forward with the tide (for instance herring in the Inverness Firth) migh or might not, be in the vicinity when a light experiment was started in an area which wa known to contain fish.

5. *Turbidity.* This varied over very wide limits. The west coast lochs had clear water where 1000 watt light could be seen from the vessel at a depth of 50 m (27½ fm) or more. In th Firth of Forth and Inverness Firth, where there are outflows from rivers, the turbidity in creased, and in the upper reaches of the Firth of Forth, near Kincardine Bridge, the 100 watt light disappeared at a depth of 1 m (3′). Under such circumstances the attractive pow of the lamps was greatly reduced. As whiting are not found in this very turbid water it wa not possible to estimate the effect of turbidity on the distance of whiting from lights.

Identification of Echo-traces

It was often possible to predict the fish species present in an experiment before sampling, by th nature of the echo-trace. These characteristic traces, obtained at anchor, do not necessarily bear an obvious relationship to the traces produced by the same species when the vessel is moving. On son occasions, however, light experiments were carried out on traces which were found after search from moving vessel and in these instances it was possible to gain experience in identification of echo-trac These results will be considered elsewhere.

DISCUSSION

Commercial Application of Light Experiments

The main purpose in conducting these light experiments was to get indications of the possible appl cation of artificial lights in commercial fishing operations in the Scottish area. The results clearly sho that some species are aggregated into dense concentrations in the vicinity of lights and so may be amenab to fishing with an appropriate gear. The biggest aggregations have been obtained with whiting, b juvenile herring and also sprats have been aggregated on a number of occasions.

An analysis of the size compositions of the whiting aggregated by lights in a number of experime showed that fish of marketable and unmarketable sizes were present in the same aggregation and th the lights were generally non-selective with respect to the size of fish aggregated within a given rang Therefore if lights are to be used in commercial fishing for whiting, selection must be effected by th gear used for capture. In the case of herring, only juveniles have been aggregated by the range of ligh used in the experiments; adult herring have exhibited a negative reaction on all occasions that ligh have been applied in the vicinity of herring shoals, and no evidence is available to show that lights caus them to aggregate. This is in conformity with earlier observations by Richardson (1952). It appea therefore that, in the North Sea herring fisheries, lights of the type so far applied have a possible com mercial application only in fisheries for juvenile herring and sprats. However, the observations made o adult herring in the Scottish area have been few and it may be that lights of other intensities and colou or beamed lights might produce aggregations.

Information on the aggregation of other commercially useful species such as cod, saithe, hake, and g and the small gadoids, *Gadus minutus* (poor cod) and *Gadus poutassou* (poutassou), which have all en observed at times during the experiments, is too scanty at present to gauge whether lights might be ed in fishing for them. It is an aim of future work with lights to extend observations to regions where ieries for cod and haddock are conducted.

The question arises of which methods of fishing used commercially would be most appropriate for tching fish aggregated by lights. The blanket net and boom net used in the experiments both have iited use, depending on good weather and suitable tidal conditions. It would seem that the most propriate types of gear would be those working on an encircling principle, e.g. ring-net or purse-ne or those with hooks, e.g. hand or long line. While hand lines proved very efficient for sampling iting aggregations, no trials could be made with ring-nets or purse-seines. The usual methods of iing for whiting in the Scottish area, by Danish seine and trawl, would not seem to be very suitable for tching fish aggregated by lights, though a mid-water trawl might be more effective. It is possible, too, at lights attached in various position on trawls and seines might reduce the number of fish avoiding e net. This warrants further study.

Other methods of capture not used in the Scottish area also present possibilities. One of these is the n pump described by Smith (1955). Such a system has been developed for small fish in the U.S.S.R. orisov 1956 and Nikonorov 1957). Another is the "set net" used by Japanese fishermen, usually near e coast in shallow water (Anon. 1955). Lights, scattered and beamed, may be used to attract the fish o the net (Sasaki 1957), the fish being attracted into the net along the light beam.

HAVIOUR

Data of a less immediately practical nature have been obtained in these experiments. The various n species differed in their behaviour to a given light such that the optimum light intensity for whiting s much less than that for clupeoids, other small fish and planktonic organisms. The effect of colour s not been gauged satisfactorily though previous work has shown that fish are probably sensitive to ra-violet light (Craig and Baxter 1952).

An interesting result (remarked on by Schärfe 1952) is the apparent dislike of fish, particularly iting, of lights coming from below. Aggregations of whiting were nearly always found below the nts and only above the light on the occasions when two lights were used at different depths. The aggregating around the upper light were then more strongly stimulated by it than they were from light below. This behaviour may be explained by the dorsal light reaction (Fraenkel and Gunn 0) where animals orientate at right angles to light. For instance v. Holst (1935) found that *Crenilabrus ratus* with both labyrinths removed would swim perpendicular to light from any direction even if it olved swimming upside down in response to light from below. With the labyrinths intact the fish uld tilt its body in response to lateral light but would not swim upside down.

It is sometimes possible to correlate the behaviour of fish in light experiments with the diurnal vements found when no artificial lights were in use. For instance, the whiting in Loch Striven (55, moved to a depth during the day where the light intensity was similar (0·17 lux) to that at which aggregated during the experiments (0·22-0·06 lux). This behaviour is in contrast to adult cod (Ellis 5) which do not make diurnal migrations of any significance.

At night juvenile whiting rise towards the surface, but it is unlikely that they will find an intensity ght comparable with that during daylight except near the surface in bright moonlight. Thus they often be adapted to a very low intensity at night but in daylight the intensity will always be much ier. It may be that this change of intensity is not great enough to demand accommodation or that ommodation takes place as the fish descend.

It is less easy to think in these terms in the case of the herring. A diurnal movement in adult herring ng to the surface at night) is well established and has been discussed for instance by Balls (1951). nardson (1952) showed that adult herring shoals in the southern North Sea tended to keep within the ie light intensity throughout the day. In the present experiments shoals of 0-group and 1-group ing varied very much in depth. For instance in the Inverness Firth the shoals might be anywhere

between 10 and 25 m (5½-13½ fm) during daylight depending on the depth of water. It seems proba that these juvenile fish are less sensitive to changes in light intensity than the adults. In one experim in Loch Nevis (37) an echo-trace, later shown to be herring (length 20-27 cm, 8-11″) was observed be anchoring at a depth of about 10 m (5½ fm) (probable light intensity at this depth about 10^3 lux). Du the subsequent experiment they were attracted by lights into intensities of 10^3 to 10^4 lux. On the ot hand, there were occasions when shoals attracted into the vicinity of bright lights at night were fo during the day at a depth where the intensity due to daylight was much lower. This might be explai by the difference between the even illumination of daylight and the "point source" used in the li experiments.

Verheijen (1956) has suggested that the attraction of fish to artificial lights is due to a "n disorientation" and that it may be compared with the reactions to light of night-flying birds and inse The mechanism of this disorientation may be as follows: provided the light is not scattered appreci the fish will be presented with an isolated source of light surrounded by a dark background. This cont which will not be met with under normal conditions, will, in effect, blind the fish unilaterally, i.e. o one eye will be stimulated by the light at any given time. Until compensation takes place, this "unilat blinding" will tend to make the fish swim in a deviating path towards the light.

This hypothesis would explain the behaviour of juvenile herring and sprats observed in these periments. In many cases they were attracted into the vicinity of the light. In turbid water, when light would be scattered, the attractive power of lights was much reduced, though this might be du attenuation. In some instances, too, fish were seen swimming in circles around the light. (Unilater blinded fish swim in circles towards the unoperated side.) It is not so easy, however, to explain behaviour of whiting, which aggregated at an optimum intensity some distance from the light, in te of a mass disorientation.

Opportunities were also taken to study the behaviour of fish when in a visible aggregation aro a light at the surface. Maeda (1951) analysed the behaviour of shoals attracted to artificial light in t of the structure of the shoal in relation to colour and intensity of light, the effect of predators, and order of arrival of different species to the shoals.

It was apparent in a number of experiments that fish found near the lights were in fact pred attracted by aggregations of prey. In one experiment (51) a shoal of sprats (8-13 cm, 3-5″) numbe at least one thousand was seen swimming against a weak tide below a 1000 watt lamp (which was below the surface). The sprats were difficult to catch as they easily evaded hand nets. Later they seen swimming closely packed at the surface around the light in an anti-clockwise circle with ra about two metres. The size of this circle gradually became reduced until the fish in extreme agita were packed in a mass around the light itself, obscuring it from view. In this condition the fish coul removed in large numbers by a hand net. It was then seen that mackerel (35-40 cm, 14-16″) were pre on this shoal. After about 15 minutes the entire shoal had been destroyed.

Herring (18-25 cm, 7-10″) were very difficult to catch with hand nets when shoaling near the surf In one experiment (37) they were stemming the tide at the surface just below a 1000 watt light. In instance whiting were preying on the herring from below. Occasionally a single whiting would be attacking the herring but most whiting, probably due to the high intensity of the light, remaine deeper water and thus the general nature of the herring shoal was not disturbed.

The general relationship between predator and prey seemed in these instances to be as fol Herring and sprats, both species attracted by bright lights, were the main prey; predators such as mack dogfish, cod and some whiting would come into the vicinity of a light to take food and then swim a again. Most whiting presumably preyed on those fish which were in the lower light intensities.

ACKNOWLEDGEMENT

We are very grateful to Mr. R. E. Craig who took part in a number of the experiments and who done much to help by supplying technical apparatus.

SUMMARY

Fifty-nine experiments with artificial lights have been carried out around the coast of Scotland tween 1953 and 1957. The main aims of the experiments have been to investigate:

1. the behaviour of fish in relation to light stimuli, and
2. the possibility of using artificial lights commercially as an aid to catching fish.

Particular attention was paid to identification and sampling the fish in the aggregations obtained lights. Apparatus used included camera, T.V., explosives and various types of net. The main species gregated were *Gadus merlangus* (whiting) 10-40 cm (4-16″) long, *Clupea harengus* (herring) 5-25 cm (2-10″) ng and *Clupea sprattus* (sprat) 5-15 cm (2-6″) long. Fourteen other fish species and seven invertebrate ecies were also sampled in light aggregations.

The brighter lights were most effective in producing aggregations.

The use of different light intensities from 10 to 100 C.P. showed that whiting aggregated at a rela- ely low optimum intensity (about 0·1 lux) away from the lights, while herring and sprats sought much gher intensities (1000-10,000 lux) and concentrated around the most powerful lights used.

It was not possible to draw any conclusions about the effect of different colours.

Vertical migration of whiting and clupeoids was studied in relation to pressure changes. The aximum percentage pressure changes observed from movements induced by lights were +100% and 49% for whiting, +180% and −73% for herring and +225% and −67% for sprats.

Vertical swimming speeds were also measured. These ranged from 1·5 to 56·0 metres/minute -180 feet/minute) for whiting, 0·8 to 36·0 metres/minute (2½-117 feet/minute) for herring and 0·8 30·0 metres/minute (2½-97½ feet/minute) for sprats.

There was little sign of accommodation to lights.

Data were also obtained on the horizontal extent of aggregations and the effect of extraneous factors ch as tide, turbidity and moonlight on the behaviour of fish.

In assessing the value of lights in commercial fishing the following conclusions were reached. Lights ght be of advantage in fishing for whiting by hand and long line in the Scottish inshore fisheries or circling nets might be adapted to catch aggregated fish. Lights would not be likely to benefit trawl seine fisheries unless experiments showed that lights attached to these gears would prevent fish escaping and the nets. Although few experiments were carried out on adult herring, no evidence is available at they will aggregate in response to artificial lights. Lights might be of use in the sprat and juvenile rring fisheries, particularly in areas where the water is clear. It is probable that the most effective ans of catching aggregations of such fish would be by pumping devices but the ring-net or purse-seine ning techniques might again be adapted to this end.

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APPENDIX

Schedule of Experiments

No.	Date	Place	Depth (metres)	Main Species Aggregated
1	23/24.2.53	W. Coast. Loch Striven	66	*Gadus merlangus*, *Clupea harengus* (0 gp) *C. sprattus*
2	6/7.3.53	W. Coast. Loch Striven	68	*G. merlangus*, *C. harengus* (0 gp)
3	11/12.3.53	W. Coast. Loch Striven	71	*G. merlangus*, invertebrates
4	8/9.6.53	N. Sea. 58°10′N 01°33′W	93	—
5	9/10.6.53	E. Coast. Cromarty Firth	31	—
6A	10/11.6.53	E. Coast. Moray Firth 57°56′N 03°08′W	53	*G. merlangus*
6B	4/5.9.53	N. Sea Turbot Bank	Drifting	—
7A	22/23.10.53	W. Coast. L. Inchard	40	? *G. merlangus*
7B	29/30.10.53	W. Coast. L. Cairnbaum	40	? *G. merlangus* ? *C. harengus*
8A	30/31.10.53	W. Coast. L. Kanaird	33	*G. merlangus*, *G. virens*, *G. minutus*
8B	2/3.11.53	W. Coast. L. Cairnbaum	42	*G. merlangus*
9	3/4.11.53	W. Coast. L. Inchard	42	—
10	2/3.12.53	E. Coast. Cromarty Firth	35	*G. merlangus* *C. harengus* (0 gp)
11	3/4.12.53	E. Coast. Cromarty Firth	35	*C. harengus* (0 gp)
12	4/5.12.53	E. Coast. Inverness Firth	26	*C. harengus* (0 gp)
13	7/8.12.53	E. Coast. Moray Firth off Burghead	42	—
14	8/9.12.53	E. Coast. Inverness Firth	27	*C. harengus* (0 gp, 1 gp)
15	9/10.12.53	E. Coast. Cromarty Firth	37	—
16	10/11.12.53	E. Coast. Inverness Firth	22	*G. merlangus* *C. harengus* (0 gp, 1 gp) *C. sprattus*
17	11/12.12.53	E. Coast. Inverness Firth	26	*C. harengus* (0 gp, 1 gp) *C. sprattus*
18	4/5.5.54	E. Coast. Moray Firth off Brora	33	—
19	5/6.5.54	E. Coast. Inverness Firth	12	—
20	6/7.5.54	E. Coast. Inverness Firth	20	—
21	7/8.5.54	E. Coast. Moray Firth, Spey Bay	12	*C. harengus* (0 gp) invertebrates
22	13/14.5.54	E. Coast. Moray Firth, off Troup Head	49	—
23	16/17.11.54	W. Coast. L. Hourn	33	*Ammodytes* spp. *Anguilla anguilla* (elvers), invertebrates
24	17/18.11.54	W. Coast. L. Sunart	27	*G. merlangus* *G. minutus* *C. sprattus*
25	29/30.11.54	W. Coast. L. Striven	40	—
26	1/2.12.54	W. Coast. Off Oban	38	—
27	10/11.12.54	E. Coast. Cromarty Firth	35	—
28	5/6.4.55	E. Coast. Moray Firth off Lossiemouth	35	?
29	6/7.4.55	E. Coast. Moray Firth off Cullen	55	—
30	26/27.10.55	W. Coast. L. Fyne	46	?
31	27/28.10.55	W. Coast. L. Fyne	57	*G. merlangus*
32	28/29.10.55	W. Coast. L. Long	46	? *G. merlangus*
33	6/7.12.55	W. Coast. L. Nevis	73	*G. merlangus* *C. sprattus* *Ammodytes* larvae, invertebrates
34	7/8.12.55	W. Coast. L. Hourn	33	*Ammodytes* larvae invertebrates
35	8/9.12.55	W. Coast. L. Nevis	73	*G. merlangus* *C. harengus* (1 gp) *C. sprattus*
36	12/13.12.55	W. Coast. L. Nevis	62	*Ammodytes* larvae invertebrates
37	13/14.12.55	W. Coast. L. Nevis	55	*G. merlangus* *C. harengus* (0 gp, 1 gp) invertebrates
38	7/8.2.56	E. Coast. R. Forth	6	—

APPENDIX—*Continued*

No.	Date	Place	Depth (metres)	Main Species Aggregated
39	8/9.2.56	E. Coast. Firth of Forth	33	*C. harengus* (0 gp) *C. sprattus*
40	10/11.2.56	E. Coast. Firth of Forth	40	*C. harengus* (larvae) *C. sprattus*
41	13/14.2.56	E. Coast. R. Forth	10	—
42	14/15.2.56	E. Coast. R. Forth	18	—
43	15/16.2.56	E. Coast. R. Forth	4	—
44	17/18.2.56	E. Coast. Firth of Forth	37	*C. harengus* (0 gp) *C. sprattus*
45	20.7.56	Atlantic. 61°01′N 08°54′W	110	? *G. poutassou*
46	1.8.56	Atlantic. 57°25′N 16°00′W	?	—
47	2.10.56	N. Sea. 55°14′N 00°13′E	82	? *Motella mustela*
48	8.10.56	N. Sea. 55°15′N 00°10′E	82-90	*Motella mustela*
49	3/4.12.56	W. Coast. L. Fyne	40	*G. merlangus* ? *G. callarias* *C. sprattus* *Ammodytes* larvae invertebrates
50	4/5.12.56	W. Coast. L. Fyne	20	—
51	6/7.12.56	W. Coast. L. Striven	31	*G. merlangus* *G. virens* *C. sprattus* *Gobius minutus* *Gasterosteus aculeatus* invertebrates
52	7/8.12.56	W. Coast. L. Striven	31	*G. merlangus* *Ammodytes* (larvae) *Gobius minutus* *Gasterosteus aculeatus*
53	6/7.2.57	E. Coast. Inverness Firth	13	*C. harengus* (0 gp, 1 gp) *C. sprattus*
54	7/8.2.57	E. Coast. Moray Firth off Nairn	11	—
55	11/12.4.57	W. Coast. L. Striven	53	*G. merlangus*
56	12/13.4.57	W. Coast. L. Striven	53	*G. merlangus*

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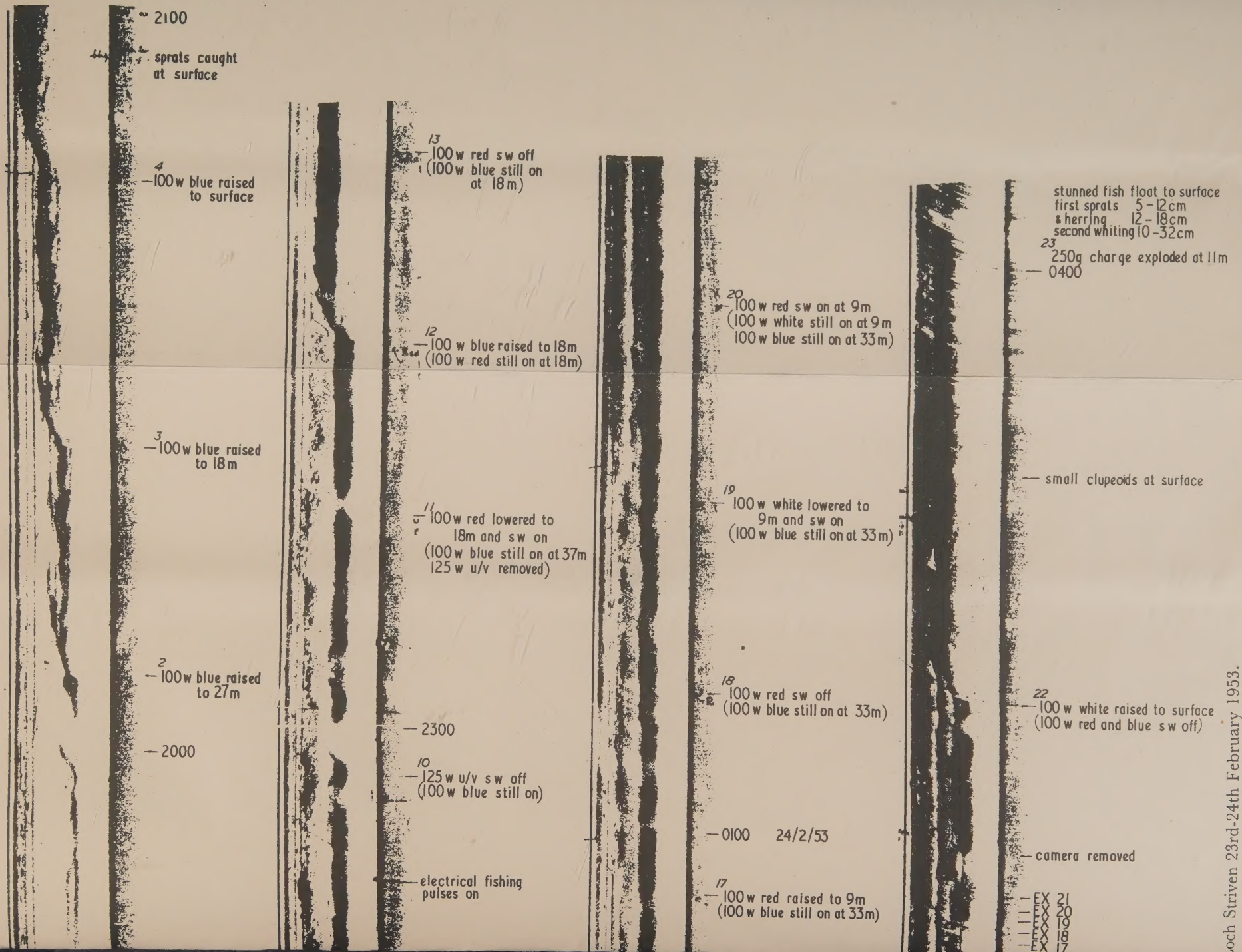
Plate I. Echo-trace of light experiment (1



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